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THE WHITWELL FIREBRICK HOT-BLAST STOVE, AND ITS RECENT IMPROVEMENTS.

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THE Whitwell firebrick hot-blast stove, for furnace use, may be seen in its three main stages of development in the accompanying drawings. Fig. 1 is the stove of 1869, the year in which it was thoroughly tested at the Consett furnaces, England; Fig. 2, the stove of 1876 and 1877, in which it was intended to reduce the cost by increasing the height; Fig. 3, the stove of 1880. Many modifications were made from time to time, generally in the direction of improvement, but the drawings illustrate the main features of progress.

In the stove of 1869 the plan was to introduce the gas at A, and pass it up and down between each alternate wall, the air in the reverse direction, passing in at B. The friction in this stove was so great, owing to the restricted area of the passages and the many reversals of the gaseous current, that it was deemed imprudent to build the stoves higher than 28′, 6″. Another reason was that the great importance of cleaning was carefully kept in view, and it was very difficult to operate any hand scraper even to this depth. For these reasons the $22' \times 28\frac{1}{2}'$ stove held the field for several years. A slight change made from this was to the $18' \times 40'$ stove, where the height was increased, but the number of walls diminished. In this stove the friction was somewhat reduced, but so was the heating surface, and although it cost a little less it was not any better.

The next important change, seen in Fig. 2, was by increasing the height to 60 feet and keeping the full number of walls in the stove. The heating surface and mass were much increased in proportion to the cost, and the friction decreased by alternating over and under two or more walls, instead of one, as formerly. This stove gave admirable satisfaction, but, although the proper doors were provided, it was very difficult to clean, owing to the long distance the scrapers had to traverse.

Stove No. 3 is a modification of No. 2. The great question

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was how to decrease the cost without imparing in any way the efficiency or durability of the stove? In this plan the gas passes up and down the stove twice, as does the blast, but in the reverse direction. Thus we have very far departed from the 1869 stove, where the ups and downs were five in number. The number of walls traversed in this case are five, while the cross or stay-walls are eleven, instead of three, as formerly. We have thus increased the area of surface very greatly, while the friction of the total stove has not been increased, since the speed of the currents has been much diminished by increasing the aggregate area of the passages.

It is a matter of much importance to have this properly proportioned, as it insures:

1st. The utilization of every foot of surface exposed.

2d. The prolonged use of the stove without cleaning.

3d. The forcible contact of the air with every heated brick, and,

4th. The thorough mixture of the gas and air while heating the stove, causing the most perfect combustion.

If the area for the passage of a limited amount of gas or air were indefinitely increased the surface exposed would be but partly utilized. We consider that an area so great that the currents are much below ten miles an hour too great to be wholly effective. This current, ordinarily called a "fresh breeze," will prevent the deposit of the light flocculent material on the walls, so highly detrimental to the heating power of the stove. Only heavy solid matter will collect, which must be scraped off. To this end we provide a swivel crane, pivoted in the centre of the stove top. The carriage of this crane can be made to operate the chain directly over any of the heating passages. To this chain is attached a heavy weighted scraper, counterbalanced on the other end of the crane beams. The scraper can be rapidly run up and down the walls even while quite hot. In fact the stove can be taken off blast, and work of cleaning immediately commenced. The chimney damper being left slightly open, all heat will be drawn away from the men at work.

The speed of gas consequent on thus limiting the area of the passages does not present any difficulty in the matter of draft. A chimney with a head of draft equal to 1 inch of water is all that is necessary, and 150′ to 175′ in height is ample. The entire friction of the stove, when on gas for normal duty, does not exceed $\frac{1}{4}$ inch of water; indeed the friction of the blast, from one end to the other, is only $\frac{1}{5}$ of an inch, the valve friction not being taken into consideration.

You will observe that, though slightly modified, the air channels

for heating the oxidizing air are in the main the same as in the older stove. The bricks being fully heated, the air in passing through the channels takes up an amount of heat which very materially aids the combustion. We might here say, that as blast-furnace gas is necessarily much reduced in combustibility, by an admixture of from 14 to 15 per cent. of CO_2, it is desirable to use all means to effect a thorough combustion. These channels in the wall may be objected to as ineffective after the first few moments, but the work of any continuous regenerative furnace will fully demonstrate that a very great amount of heat can be taken up by air having a brick partition between it and the flame. We always insure a sufficient strength in the walls after the passages are deducted, and these openings are not, therefore, detrimental to the strength of the stove. Another means lately introduced to aid the combustion of the gas is to introduce a jet of heated air from the stove then on blast, admitting this blast through a number of small tuyeres, placed in the bottom of the combustion-chamber. This we have found amazingly effective.

In the "ideal working" of the blast furnace, where all the carbon is burned at the tuyeres to CO, and all reduction is effected by the oxygen of the ore burning this gas to CO_2, 5.7 pounds of air will be required for each pound of carbon charged. In this case (were it possible) a good grade of ore could be smelted with .506 pound of carbon to the pound of iron, actual reduction requiring by the above assumed process .312 pound of carbon, and $.312 \times 8080 = 2521$ calories. The portion of this heat at the tuyeres is $.312 \times 2473 = 771.57$ calories (C to CO), and $.312 \times 5607$ in zone of reduction (the CO to CO_2). The total calories required, independent of the heat from the blast, being about 3000, there is further required in the zone of combustion, 479 calories, which require .194 pound carbon, burned to CO. This latter passes away in that condition. The total carbon, therefore, consumed from the fuel is $.312 + .194 = .506$ pound, which multiplied by 5.7 pounds gives 2.884 pounds of air to the pound of iron. This measure of economy need not be expected to be reached until our present mode of reduction can be entirely changed. It is however the smallest amount of air possible for a 50 per cent. ore, using 25 per cent. of lime. By the aid of the Whitwell hotblast this same quality of ore has been through a year's work reduced with .819 pounds of carbon to the pound of iron, which required 3.75 pounds of air; the proportion of CO to CO_2 being much smaller than in the case assumed. Where, however, an ordinary economy of product with high heats is attained, say 1 pound

of carbon (1.15 pounds of coke), to the pound of iron, the weight of air would scarcely exceed 4.5 pounds. For practice, however, in figuring the heating surface of the stoves, we assume $5\frac{1}{2}$ pounds of air to the pound of iron, and as the air at ordinary atmospheric temperatures weighs .076 pounds per cubic foot, 72 cubic feet of air are required to make 1 pound of iron; or, allowing 23 hours' blowing for a day's work, 117 cubic feet of air per minute are required for 1 ton of iron per day. From actual tests we know that 5 feet of surface in the plant of stoves is sufficient for 1 cubic foot of air per minute, but allowing 20 per cent. loss in engines, etc. (a fair allowance where machinery is good), 4 feet of surface may be provided in the stoves to 1 of air per minute, counting piston displacement. The surface, therefore, required when good ores are to be smelted, will be $117 \times 5 = 585$ feet per ton of iron per day.

We must here call attention to a matter of some importance, with regard to the Whitwell stoves. If the stoves are to be placed at an old furnace, an increased outpnt may be assumed of 70 to 100 per cent. The only instances in which this has not been the case is where stoves of insufficient capacity have been put up. Where ordinary cast-iron pipe stoves have made a product with certain ores and fuel, and it is proposed to erect a furnace with Whitwell stoves they must be built with a view to this increased output. Thus we expect for a 15-foot coke furnace 100 tons of iron per day, or if the ores are especially good a make of 115 tons can be reached, and where the ores are lean and silicious 75 tons is all that can be expected. We wish to have it well borne in mind that the leaner the ore the more air per ton is required, and *vice versa*, and it would be approximately correct to calculate the size of the stoves based upon the amount of ore used. Or the following method may be used, which avoids the extremes of basing the size of the stoves upon the air per minute with the assumption of a fixed quantity per pound, and the percentages of the ores. Multiply the number of pounds of ore required per pound of iron by 190, and add the constant 220. This will equal the total stove heating surface per ton of iron per 24 hours. This, again, depends upon the cubical contents of the blast furnace, since, ordinarily, the leaner the ores the less the product; and as the leaner ores require the greater amount of air per unit of iron, therefore the greater amount of heating surface is required. The American coke practice with high heats has reached the production of 1 ton of iron per 24 hours to 90 cubic feet of furnace contents with 60 per cent. ores. Then, as

above, $190 \times 1\frac{2}{3}$ tons of ore to ton of iron $= 317 + 220 = 537$, which divided by $90 = 6$, nearly. We use 6.5 as a multiplier; that is, we multiply the cubical contents of the furnace by $6\frac{1}{2}$ to obtain the heating surface of the stoves, and this result will be nearly correct for any character of ore. For small furnaces this had better be somewhat increased, and for larger ones it may be slightly decreased, since small furnaces are greater producers per unit of contents. We have thus a "rule of thumb" for calculating the stove surface required.

Let us here call attention to a bad practice of comparing furnaces by the height and the diameter of the bosh. With these two measurements the cubic capacity may be twice as great in one case as the other. We have calculated 16-foot and 13-foot furnaces, and found them practically alike. The cubical capacity comprises all the dimensions, and is a much more reasonable basis of comparison than any single measurement. A comparison of duty should be made by stating how many cubic feet are required to make a ton of iron in twenty-four hours.

In this connection we should explain how so many furnaces have been supplied with altogether too little stove power. The English furnaces have an average output of one ton of iron per twenty-four hours per 250 feet of cubic capacity, the range being from 170 to 430. Mr. Whitwell, during his lifetime, had control of this county's business, and he did not or would not recognize the economic consideration of large output having greater importance here as compared with the English practice. His recommendations, therefore, based upon furnace size, were always too small for high heats in American practice. Few of the old type stoves, with their limited heating surface, had anything like enough power to do the work expected of them. Thus the stoves were said to do little better than the cast iron, as far as make and output were concerned; but none who had them ever regretted putting them in since the economy of maintainance alone was full recompense for the outlay. Many stove plants have now been in use for years, and have not cost a dollar since their erection, and not one of them has cost anything of any moment.

It is often asked, can a furnace afford gas enough to supply these stoves and give a heat of 1400° F. to the blast in addition to raising the necessary steam? As this is a vital question I will endeavor to answer it satisfactorily. It is no use to save the fuel in the furnace, if what is saved must be expended outside, except perhaps a cheaper grade might be used under the boilers. Practice has proved that

any well-appointed furnace, even with good economy of fuel, produces gas in sufficient quantity and of good enough quality to raise all steam required and heat the blast in cast-iron pipes to 900° F. For a unit of blast we will assume that the same amount of steam is required when either high heats or ordinary heats are used, and we will, therefore, only compare the amount of gas necessary to raise the blast temperature in the one case to 900°, and in the other to 1400° F. The gas from a blast furnace working economically may be taken to be

$CO_2 = 17.25$ per cent.
$CO = 25.25$ "
$N = 57.50$ "

The temperature produced by the combustion of this gas is that due to the further oxidation of the CO less the heat absorbed by the CO_2 and N and air introduced for the combustion.

Weight of gas to be burned, say, ...	100.
Add air required to burn the 25.25 CO to CO_2 . . .	62.6
Add for air of dilution, ...	40.4
	203.0

The temperature, therefore (specific heat, being .24), is

$$\frac{10.82 \times 5600}{203 \times .24} = 1243° \text{ C} = 2270° \text{ F.}$$

This disregards the initial temperature of the gas and air. This 203 is twice the weight of the gas consumed, and as the blast and gas are in the proportion of 1 to 1.35 nearly, the amount of heat produced by the combustion of all the gases would be equal to all the blast heated to a temperature $1.35 \times 2 \times 2270°$ F. $= 6129°$ F. If, therefore, all the heat of the gases could be imparted to the air only $\frac{900}{6129} = 14.7$ per cent. would be required to heat to 900°. But to generate 900° F. in a cast-iron stove with the ordinary degree of rapidity the escaping gases must go off at 1200°, that is only 1070° of the 2270° can be made available, requiring 31.1 per cent. of the gases burned in the ovens instead of 14.7 per cent. The heat lost by radiation from the walls of the ordinary cast-iron ovens is very great, raising the total combustion to nearly 50 per cent. of the gas.

This same reasoning applied to the Whitwell stoves shows that $\frac{1400}{6129} = 22.8°$ of all the heat of the consumed gases is returned to the furnaces, and as the escaping temperature is only 400°, 2270° — 400 = 1870° F. are available for heating the blast, and 2270

$\times$ 22.8 $\div$ 1870 = 28 per cent. To this, as before, must be added the heat lost by radiation from the stoves which, with their heavy walls and the recurring cooling action of the blast, never attains a temperature of more than 150° on the average. In fact, the naked hand can be held on the casing in many places. It is, therefore, fair to assume that the loss by radiation cannot be anything like what it is in the ordinary pipe stove, and 35 per cent. of the gas will suffice to raise the blast to 1400° F., which is about the amount obtained by measuring the gas currents. In any view, however, it is clear that less gas is required to raise the temperature in a Whitwell stove to 1400° F. than to 900° in the best style of a cast-iron pipe stove.

The above 35 per cent. of the gas will weigh in units of blast 35 per cent. $\times$ 1.35 = .4725, and multiplied by 2 = .945 gives the weight of the products of combustion, and as this amount is used in two stoves at a time, this quantity (.4725) passes through each.

The 21′ $\times$ 60′ stove has a heating surface of 29,000 square feet, and three of these will have 87,000 square feet, which divided by 6.5 gives 13,538 cubic feet of furnace capacity. But as in large furnaces this may be increased, as above stated, our estimate is for a furnace of 15,000 cubic feet capacity or for a product with rich ores of 150 tons of iron per day, equal to 100 cubic feet of furnace capacity to the ton of iron. According to our figures 150 $\times$ 117 = 17,550 cubic feet of air per minute, and that multiplied by 5 = 87,750 square feet of surface in the stoves, which nearly tallies with the former estimate. Somewhat less air than the above is required for this amount of iron when economy of fuel is made the prime object.

The proportion of the several passages through which the gas and air passes in these stoves has been a matter of much study. We will call attention to these currents which serve so well to keep the walls clear of fine light dirt. In the first passage of the blast the aggregate is 20.8 square feet, and the surface of the openings is 114 feet linear. As the friction is proportional to the surface and the square of the velocity, we multiply by these factors to get a unit of resistance, so that the entire resistance shall be the least possible, and the the mass the greatest possible. Volume of air = 17,750 feet per minute, divided by 20.8 = 853 velocity per minute, or 14′.2 per second, $14.2^2 \times 114 = 22{,}988$ units of resistance (neglecting the compression of the air). In the second passage the resistance is 20,310, and in the third 18,934, since they are made freer to compensate for the expansion of the air by the heat taken up. The last passage or com-

bustion-chamber has an area of 35.5 square feet with only 52 feet of surface linear, measured around its walls, this chamber being especially designed for the combustion of the gases. It is evident from these data that the flow of the gas being but one-half the quantity of the air, the up and down movements, subdividing the large heating chamber into three parts, cannot be any detriment in causing too much friction to the currents; and when we find less than $\frac{1}{4}$ inch of water as the actual friction in practice, we feel safe in claiming the following important advantages derived from this subdivision.

1. The complete contact of the air and the brick surface.
2. The burning gas comes in contact with every brick exposed.
3. The light flocculent material is carried on by the current, and is not deposited on the brick walls to prevent them from absorbing the heat.

These stoves have been greatly simplified in construction, being built almost entirely of 9-inch ordinary-sized brick. The shapes seen on drawing (Fig. 3) are very simple and easily made, and the number needed of each, marked on it, shows how few are required. Further, the double passage that we have just referred to enables us to use a common cheap grade of firebrick in the up and down passages next the chimney valve, as the first flush of heat is taken up in the combustion-chamber and the first down passage. This effects a very considerable saving in the construction of these stoves. The arches below are a thorough network of brick and firebrick only, and are so short in their span that it is impossible for them to fall in. The base of the centre wall is greatly increased in width to compensate for the bricks removed to form the arches across it. These arches are numerous and small, and induce a thorough spreading of the gas and blast.

As before mentioned, the product of the furnace is much increased by the application of the superheated air, and to show that such is a natural sequence we would refer to I. Lowthian Bell's report of the Consett furnaces when the Whitwell stoves maintained a constant temperature in the blast of 1324° F.* The furnaces were almost identical; the material the same; ore, fuel, and limestone; but one was blown with air at 850° F. and the other with air at 1324° F. The furnace with the air at 850° F. required 22.75 cwts. of coke to make a ton of iron, while the one with air heated to 1324° F. made the iron with 18 cwts., a saving of 4.75 cwts. to the ton, or

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* Chemical Phenomena of Iron Smelting, page 161.

21.3 per cent., attributable to nothing save the heat of the blast. The product was really the same both in quantity and quality, but the furnace with 850° air required 5.07 pounds of air to the pound of iron, while the other required only 3.75 pounds. The fact of the make being the same is easily explained, when it is known that the same blowing power was used for both furnaces. The resistance to highly heated air in passing in at the tuyeres being much greater than that of the moderately heated, less would therefore enter the same tuyere area. Both these furnaces had a tuyere area of 80 square inches, and Weisbach's formula for resistance would show that as 5 pounds entered the one set of tuyeres at a temperature of 850°, only 3.77 pounds of air would enter the other, all other things being equal, which they must have been, since these proportions are almost exactly the same as the air received by the furnaces. Had the blowing power been independent and the same amount of air been injected into each furnace in a given time, the relative production would undoubtedly have been 5 for the furnace with superheated air to 3.75, for the other, the make rising from 60 tons per day to 80.

This brings us to what may seem to some at first sight rather difficult to believe, namely, the construction of a furnace plant with Whitwell stoves, royalty, and all, costs no more money than when a fair plant of cast pipe stoves is put in. A blast furnace for given materials is large or small according to the product, and to say it is an 80-ton furnace, a 60-ton, etc., is more to the point than to give any of the dimensions. The diameter of bosh, cubic contents, size of engines or boilers, are only the details of the whole, whose duty is some uncertain quantity of pig metal. Taking these English data (and far better results can be shown than these), if the same engines, boilers, buildings, and furnace proper can be made to produce 80 instead of 60 tons per day, without being any more tasked, they are unquestionably worth $33\frac{1}{3}$ per cent. more money. We will assume, therefore, for comparison, these parts of a certain furnace to produce a stated quantity of iron to cost $100,000, and with the cast-iron stoves to cost $120,000. The Whitwell stove plant with chimney and flues will not cost over $50,000, or a total of $150,000. But as this latter for actual output is worth one-third more than the former, its relative value would be $120{,}000 + \frac{120000}{3} = \$160{,}000$. Or, to take it the other way. If the machinery, etc., all regulated by amount of air required, could be reduced in the ratio of from 5 to 3.75, and

with the aid of the stoves still make the same amount of iron, and this saving added to the cost of a cast pipe stove plant, there would be more than enough money to build a fine plant of Whitwells.

The above is by no means our best results. The application of the stoves to existing plants has fully doubled the output in several instances. Why is this great increase of output the result of the application of the Whitwells? By blowing superheated air into the furnace a combination of several advantageous points results. Less fuel is used per ton, therefore there is more ore in the furnace. Less blast is used, therefore less heat is carried away in the gases. The sensible heat of the gases is always lower, and part of this loss is prevented. The more highly heated the blast the greater affinity its oxygen will have for the incandescent carbon in the hearth, therefore the more rapid the formation of the CO; and the more rapid the combustion the more the area of combustion is confined, and the sooner the zone of reduction will be established. The more intense the combustion the more limited the zone of fusion, the intensity of the heat being greater but the quantity of heat less. The work performed where high heats are employed is done quickly and well, but the heat is very rapidly reduced to such a point that reduction can actively commence and be perfected in a region much lower down in the furnace. Thus a low furnace will do the same work as a much higher one, and a high one can be proportionately pushed, so that in either case a great economy of fuel results.

The variation in the temperature of the blast from the stove, from the time it is first put on till taken off, an hour afterwards, is objected to by some furnacemen. This change is very small with good-sized stoves; still we have devised a means of providing against any change. The device by which this is effected is based upon the difference in the resistance to the passage of a certain quantity of air at different temperatures. A freely moving piston forms a valve, the upper end of which is pressed upon directly by the cold air, and the lower end by the heated column which has passed through the stoves, valves, and part of the pipes. If the air is much heated, the pressure in this latter pipe is so much less by the extra resistance due to that temperature, and the result is a depression of the valve by the cold air column, and an admission of cold air to regulate the temperature of the blast entering the furnace. When the temperature in the stove diminishes the balance of these pressures causes the valve to rise and reduce proportionally the amount of cold air. By weighting the lever attached to the valve a constant temperature can be

maintained at the tuyeres. We are endeavoring to perfect a pyrometer operated by the difference in friction of hot and cool air, and think we can succeed.

It is easy to demonstrate what an immense quantity of heat a plant of these stoves contains, and what a small proportion of this is taken away by each hour's run. The only reason there is any noticeable difference in the temperature of the blast is, that a slight film of surface is more highly heated than the body of the bricks; but, the body of the bricks being heated through and through, the heat is very slowly taken away, and the surface temperature can be well kept up for a very long time when sufficiently large stoves are in use, as herein recommended. As already stated, one stove, 21 feet diameter, and 60 feet high, has a surface of 29,000 square feet. This has 17,550 cubic feet of air passed through it per minute, or 1,053,000 per hour, the length of ordinary air-blow. The weight of this air is $1{,}053{,}000 \times .076 = 80{,}028$ pounds, which, multiplied by .237 (specific heat) $\times$ 1300° F. (less temperature of cold air pipe) $= 24{,}654{,}500$ pound-units per hour. As the specific heat of firebrick may be taken at .2, and the average thickness of the walls 6 inches, compared with heating surface (by averaging the 9-inch division walls and the small wall crossings), then $29{,}000 \times .2 \times$ 3-inch (half wall) $\times$ 10 (weight of square foot of brick 1 inch thick in pounds), we have the units of heat per degree of wall $= 174{,}000$. But the hour's blast absorbs 24,654,500 units, requiring a lowering of the temperature of 140° F. of the mass of the walls under consideration. This does not, however, represent the diminution of the blast temperature, as the greater reduction of temperature in the walls is toward the cold end, leaving the heat of the hot end well up to the maximum. This reduction, however, is the great safeguard to the longevity of the stove. If the gas were admitted continuously, burning among the heated walls, the temperature would go on increasing, as long as a balance could be maintained in its favor against radiation and heat of the escaping gases, and the destruction of the walls would inevitably result. But in each three hours one hour is taken up in carrying away the heat given to this stove during the other two, and as a consequence the walls never attain a temperature that can injure them. Our stoves, therefore, are everlasting. This heat, imparted from the walls of the stove and given up to the blast, has to traverse through the bricks, an average distance of $1\frac{1}{2}$ inches, since the wall is 6 inches thick, and acted one on each side. (If, as is supposed by some, the walls are only heated and cooled half

an inch, we would ask, where does the heat come from to heat the volume of blast, as ordinarily proportioned to the stoves.) Since the quantity of heat conducted through solid bodies is inversely proportional to the distance travelled, and directly proportional to the difference in temperature, and as one inch of firebrick has speed of conduction per minute of .33 units to the square foot to each degree of Fahrenheit, for $1\frac{1}{2}$ inches thick, the amount will be .22 units; and since the number of units per minute is 610,910 ÷ 29,000 = 21 per minute per square foot of surface 21 ÷ .22 = 95°, the difference between the heat at the surface and the heat at the centre of the walls. If the walls were made thinner than 6 inches, the difference in temperature would be less; but the total heat of the wall would be relatively decreased; and as the above differenee is very slight, compared with the entire heat of the mass, this mass should not be decreased or sacrificed to heating surface.

Mr. Whitwell held there was no economy in decreasing the walls below 9 inches, claiming that the surface was sufficient to absorb all the heat these walls could spare for regular work; but we consider that the heating surface cannot be too great if the mass is not sacrificed in getting it. We have adopted the thickness of $4\frac{1}{2}$ inches for the thin walls, and 9 inches for the dividing walls, as bricks lay more cheaply in this shape, and because it is the best, or nearly the best, proportion between surface and mass.

It would, of course, be an easy matter to construct these stoves with 2-inch walls, and thus, with less brick mass, and the same iron shell and valves, obtain perhaps 70 per cent. more heating surface. But, from the foregoing considerations, mass seems preferable to surface. At least the latter should not be inereased at the expense of the mass. We think there is sufficient conductivity in firebrick for an average thickness of 6 inches, heated and cooled alternately on each side, and that the surface so obtained is sufficient to abstract and utilize all the heat from the mass to its centre, and thus produce a practically uniform temperature in the blast.

An objection sometimes offered to the use of high heats is, that it injures the quality of the iron, and to answer broadly that it does not would not be accepted as conclusive. But we can, nevertheless, say, without hesitancy, that far from injuring the iron the quality of the iron is improved. The facts bear this out, but we give the following reasons why it should be so. The following materials are generally supposed to be detrimental to iron: Phosphorus, sulphur, and silicon. The first cannot be removed even in part by any

known processes in the blast furnace. The seeond may, by heavy liming, be carried into the slag to a great extent, if it is not volatillized in the upper part of the furnaee; but it is generally reeognized that high or low heat in the blast has little or nothing to do with the presenee of sulphur in the pig. It has been generally supposed, however, that high temperature increases the amount of silicon in the pig. This belief grew out of the eontrast of cold-blast and hot-blast charcoal iron, the former having about $\frac{1}{2}$ per eent. and the latter from 2 to $2\frac{1}{2}$ per cent. as ordinarily made in the old-style eharcoal furnace process. But the fact is in neither case should there be more than the smaller amount of silieon in the pig with eharcoal for fuel.

All the silica can be fluxed with a proper admixture of lime before its reduetion can take place, exeept that portion which is covered and protected by the earbon of the fuel, that is to say, the siliea of of the ash. This ash it is which causes the trouble in all light, weak, and highly silieonized irons. When fuel high in ash is charged into the furnaee do not blame the furnaee manager, for he eannot make strong iron; but if your fuel ash is low, and the iron weak, inerease the burden or lime, or both, as there is no other trouble. High temperature of the blast intensifies the heat of the hearth but only in a very slight degree, but it promotes economy of fuel to a very marked degree. It also reduces proportionally the eonsumption of the fuel in the hearth, since all the carbon deposition in the reducing zone will expose to the action of the flux the ash whieh was eontained in that portion of the fuel. If all the ash of an average coke were to deseend to the tuyeres, and $1\frac{1}{2}$ tons of eoke were used for a ton of iron, the iron might eontain from 6 to 7 per cent. of silieon, but by using high heats the coke can be redueed to one ton and a large proportion of the carbon and ash separated in the preparatory action of the furnace.

DISCUSSION.

Mr. Birkinbine: Mr. President: Do I understand the gentleman to claim that with two furnaees of equal size and proportions, similarly equipped, using the same ore, flux and fuel, and operated under the same management; in faet, alike in all respects, except that one was supplied with Whitwell stoves, while the other used good iron pipe stoves that the one equipped with Whitwell stoves would produee 60 to 70 per eent. more pig iron than the furnaee having iron pipe stoves and show corresponding reduction in fuel consumption?

MR. GORDON: That is what I intended to say and it can be verified.

MR. BIRKINBINE: I regret that I was not aware of the purport of this paper, so that I might have come prepared with actual data for which under the circumstances I must trust to memory. But I do not feel that we should allow the statement that the use of the Whitwell stoves will augment the product of a given plant 60 to 70 per cent. to pass unchallenged. To no one person do the blast-furnace managers owe more than to the late Thomas Whitwell, for it was he who taught us the true value of a hot-blast in controlling the operations of a blast-furnace. Up to the time his stoves were presented for public consideration, our furnace managers had treated the hot-blast stoves more as an accessory to the plant than as an essential feature with which to control and operate it, but I submit that the claims made for the superiority of the Whitwell stoves have not been substantiated in American practice. In a paper presented at the Washington meeting five years ago, I claimed that, if the same amount of study and attention was devoted to the construction of iron pipe stoves as is bestowed upon the Whitwell plants, and if an equal amount of care were exercised in watching the iron pipe stoves as is demanded for the firebrick stoves, the claim for superior durability would have little foundation. You, Mr. President and many of the gentlemen now present, are well aware that it has been the too prevalent practice to allow an iron pipe stove to care for itself. An occasional inspection to see that the gas was burning, was considered sufficient, and the pipes were subject to sudden changes of temperature by throwing open the doors when the oven was considered too hot, or when the furnace was blowing out, causing the pipes to check and crack. It has not come within my experience to find many burned pipes, although I have examined a large number which have been removed from ovens. The cracks indicate that they are damaged or destroyed by sudden or extreme changes of temperature.

As to the durability of iron pipe stoves, permit me to cite an example or two. About two months ago I inspected an iron pipe stove which had been constructed in 1860 and had been in almost constant use, and the proprietor informed me that during these twenty years of use not a pipe or brick had been removed from this oven. I am at present rebuilding the firebrick arches of the combustion chambers of an iron pipe stove. These arches were cut in ridges by the gases, the brick cindered, and 15 inches of this cinder had accu-

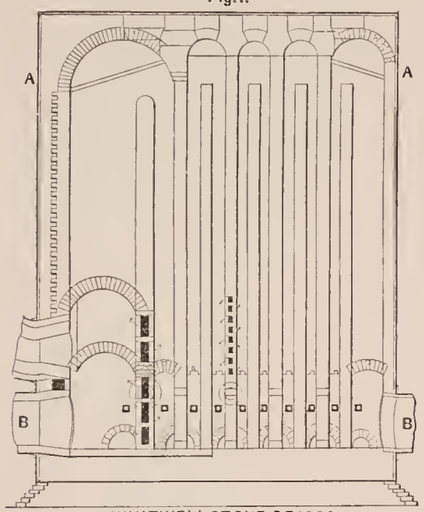
mulated on the bottom of the chambers, yet we have not discovered a single defective pipe although they were placed just above these chambers which show the action of the intense heat so strongly. Other instances of durability could be mentioned if time would permit.

Concerning the fuel economy I cannot speak as definitely on the coke practice as on that of the anthracite furnaces, but while in Pittsburgh I found that the work done at the Eliza and Soho furnaces with iron pipe stoves compared very favorably when size of furnace, quality of stock, and product were considered, with other furnaces using the Whitwell stoves.

As to the results with anthracite furnaces I know that to-day the Cedar Point furnace at Port Henry, N. Y., 17 feet × 71 feet, notwithstanding it has 4 Whitwell stoves under efficient management, is not making as much pig iron, nor working on as low fuel consumption as the Warwick furnace which is smaller, 15 × 55, and uses leaner ores. During our Wilkesbarre meeting in 1877 an opportunity was given to compare the contemporaneous working of the Port Henry and Scranton furnaces using the same ore and coal, and the statements which were then offered for examination showed no perceptible difference between the furnace employing superheated blast and blast at 800° from iron pipe stoves.

These facts are presented as they occur to me now in this crude manner. I would not be considered as detracting from the value of any improvement in blast-furnace construction or operation. I have no financial or personal interest in any form of hot-blast stove, and have no pet theories, but I insist that within our present knowledge, the firebrick stoves have not developed the economy of fuel claimed for them, and I very much doubt if Mr. Gordon can name any three furnaces having Whitwell stoves which use anthracite coal, or anthracite with a small mixture of coke, which can show a record either as to amount of iron produced or economy of fuel consumption, which will not compare unfavorably with the work now being done at the furnace of the Pottstown Iron Company, managed by our member, Mr. Janney; the Warwick furnace managed by our member, Mr. Cook; and the North Lebanon furnace operated by our member, Mr. Brock. The mixture of ores at the first two named furnaces run from 38 to 42 per cent., and at the latter plant all Cornwall ore is used, which is highly sulphurous, and averages less than 50 per cent.; and all three have iron pipe stoves.

Fig. 1.



WHITWELL STOVE OF 1869
22 ft. X 28 ft. 6 in.

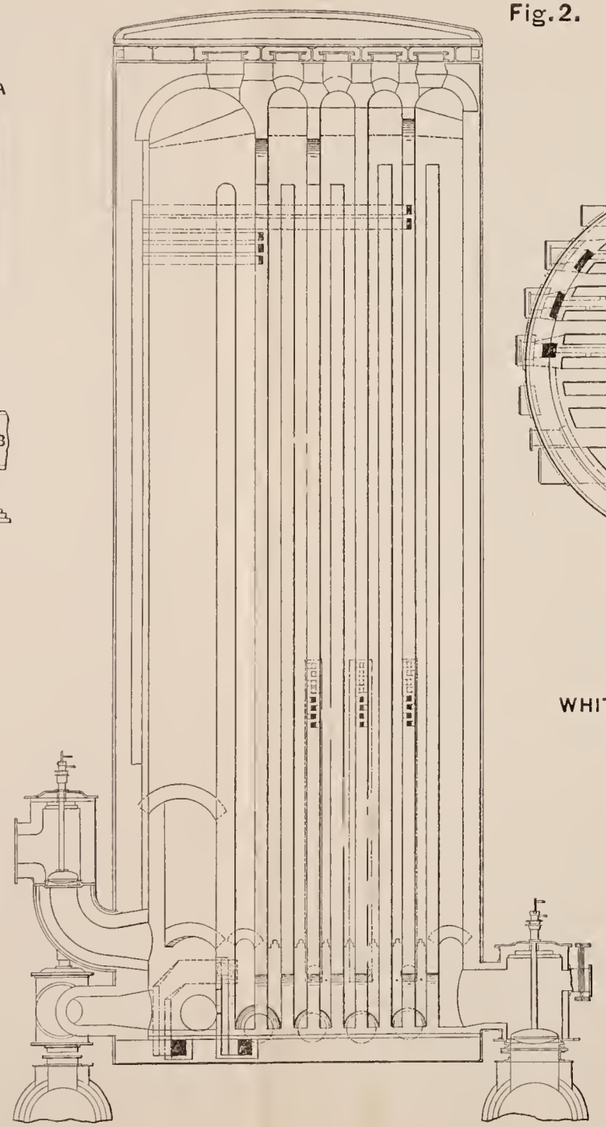
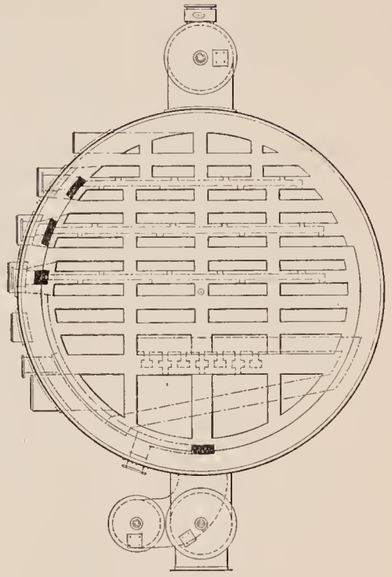
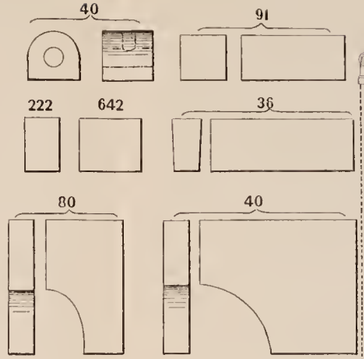


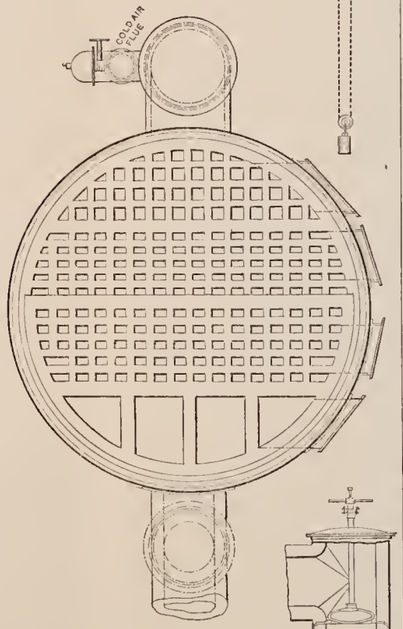
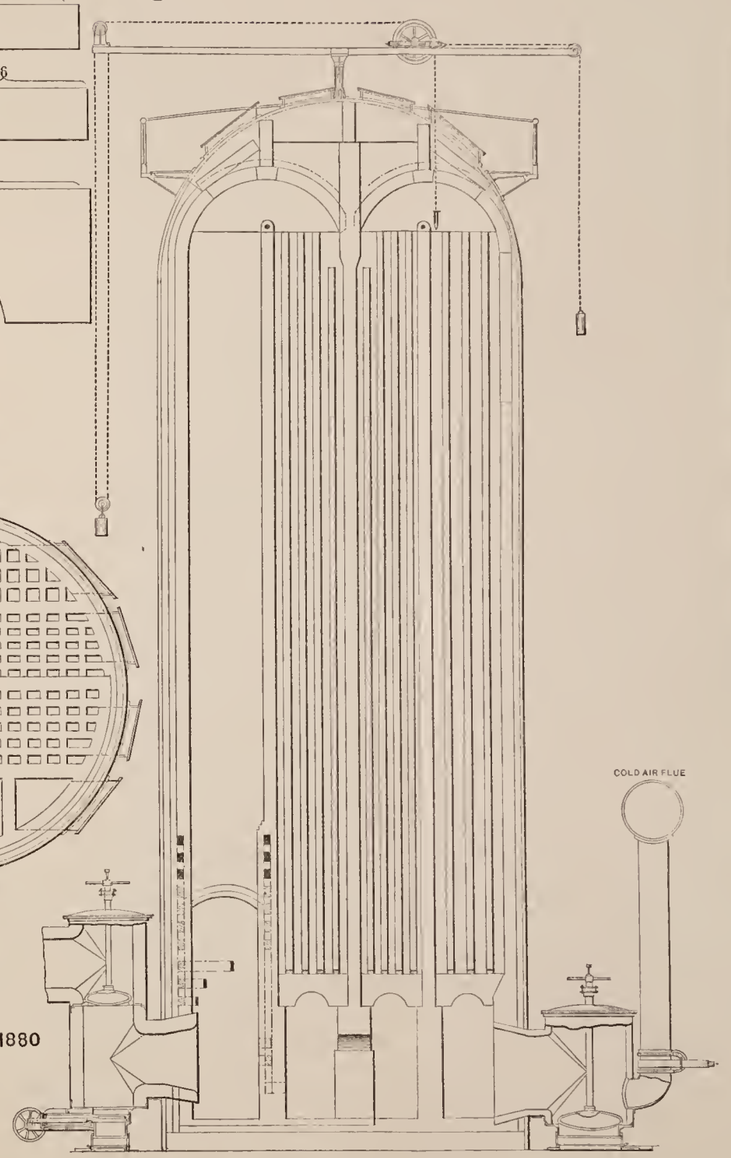
Fig. 2.



WHITWELL STOVE OF 1876
22 ft. X 60 ft.

Fig. 3.





WHITWELL STOVE OF 1880
21 ft. X 60 ft.